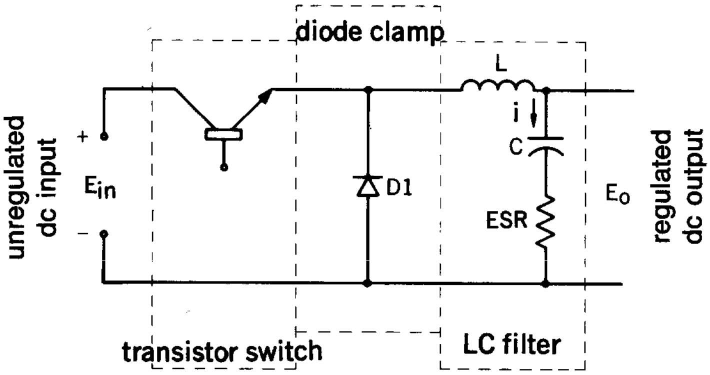
INDUCTOR CORE SIZE SELECTION (using core selector charts)

DESCRIPTION



A typical regulator circuit consists of three parts: transistor switch, diode clamp, and an LC filter. An unregulated dc voltage is applied to the transistor switch which usually operates at a frequency of 1 to 50 kilohertz. When the switch is ON, the input voltage, E_{in}, is applied to the LC filter, thus causing current through the inductor to increase; excess energy is stored in the inductor and capacitor to maintain output power during the OFF time of the switch. Regulation is obtained by adjusting the ON time, t_{on}, of the transistor switch, using a feedback system from the output. The result is a regulated dc output, expressed as:

$$E_{out} = E_{in} t_{on} f \quad (1)$$

COMPONENT SELECTION

The switching system consists of a transistor and a feedback from the output of the regulator. Transistor selection involves two factors — (1) voltage ratings should be greater than the maximum input voltage, and (2) the frequency cut-off characteristics must be high compared to the actual switching frequency to insure efficient operation. The feedback circuits usually include operational amplifiers and comparators. Requirements for the diode clamp are identical to those of the transistor. The design of the LC filter stage is easily achieved. Given (1) maximum and minimum input voltage, (2) required output, (3) maximum allowable ripple voltage, (4) maximum and minimum load currents, and (5) the desired switching frequency, the values for the inductance and capacitance can be obtained. First, off-time (t_{off}) of the transistor is calculated.

$$t_{off} = (1 - E_{out}/E_{in\ max})/f \quad (2)$$

When E_{in} decreases to its minimum value,

$$f_{min} = (1 - E_{out}/E_{in\ min})/t_{off} \quad (3)$$

With these values, the required L and C can be calculated.

Allowing the peak to peak ripple current (Δi) through the inductor to be given by

$$\Delta i = 2\ I_{o\ min} \quad (4)$$

the inductance is calculated using

$$L = E_{out}\ t_{off} / \Delta i \quad (5)$$

The value calculated for Δi is somewhat arbitrary and can be adjusted to obtain a practical value for the inductance.
The minimum capacitance is given by

$$C = \Delta i / 8 f_{min} \Delta e_o \quad (6)$$

Finally, the maximum ESR of the capacitor is

$$ESR\ max = \Delta e_0 / \Delta i \quad (7)$$

INDUCTOR DESIGN

Ferrite E cores and pot cores offer the advantages of decreased cost and low core losses at high frequencies. For switching regulators, F or P materials are recommended because of their temperature and dc bias characteristics. By adding air gaps to these ferrite shapes, the cores can be used efficiently while avoiding saturation.

These core selection procedures simplify the design of inductors for switching regulator applications. One can determine the smallest core size, assuming a winding factor of 50% and wire current carrying capacity of 500 circular mils per ampere.

Only two parameters of the design application must be known:
(a) Inductance required with dc bias
(b) dc current.

1. Compute the product of LI^2 where:
   L = inductance required with dc bias (millihenries)
   I = maximum dc output current = $I_{o\ max} + \Delta i$

2. Locate the LI^2 value on the Ferrite Core Selector charts on pages 4.15 to 4.18. Follow this coordinate in the intersection with the first core size curve. Read the maximum nominal inductance, A_L, on the Y-axis. This represents the smallest core size and maximum A_L at which saturation will be avoided.

3. Any core size line that intersects the LI^2 coordinate represents a workable core for the inductor if the core's A_L value is less than the maximum value obtained on the chart.

4. Required inductance L, core size, and core nominal inductance (A_L) are known. Calculate the number of turns using

$$N = 10^3 \sqrt{\frac{L}{A_L}}$$

where L is in millihenries.

5. Choose the wire size from the wire table on page 5.9 using 500 circular mils per amp.

Example.

Choose a core for a switching regulator with the following requirements:

E_O	= 5 volts
Δe_o	= .5 volts
$I_{o\ max}$	= 6 amps
$I_{o\ min}$	= 1 amp
$E_{in\ min}$	= 25 volts
$E_{in\ max}$	= 35 volts
f	= 20 KHz

1. Calculate the off-time and minimum switching, f_{min}, of the transistor switch using equations 2 and 3.

$t_{off} = (1 - 5/35)/20{,}000 = 4.3 \times 10^{-5}$ seconds and

$f_{min} = (1 - 5/25)/4.3 \times 10^{-5}$ seconds = 18,700 Hz.

2. Let the maximum ripple current, Δi, through the inductor be

$\Delta i = 2(1) = 2$ amperes by equation 4.

3. Calculate L using equation 5.

$L = 5\ (4.3 \times 10^{-5})\ /2 = .107$ millihenries

4. Calculate C and ESR max using equations 6 and 7.

$C = 2/8\ (18700)\ (.5) = 26.7\ \mu$farads

and ESR max = .5/2 = .25 ohms

5. The product of $LI^2 = (.107)\ (8)^2 = 6.9$ millijoules.

6. Due to the many shapes available in ferrites, there can be several choices for the selecton. Any core size that the LI^2 coordinate intersects can be used if the maximum A_L is not exceeded. Following the LI^2 coordinate, the choices are:

(a) 45224 EC 52 core,	A_L 315
(b) 44229 solid center post core,	A_L 315
(c) 43622 pot core,	A_L 400
(d) 43230 PQ core,	A_L 250

7. Given the A_L, the number of turns needed for the required inductance is:

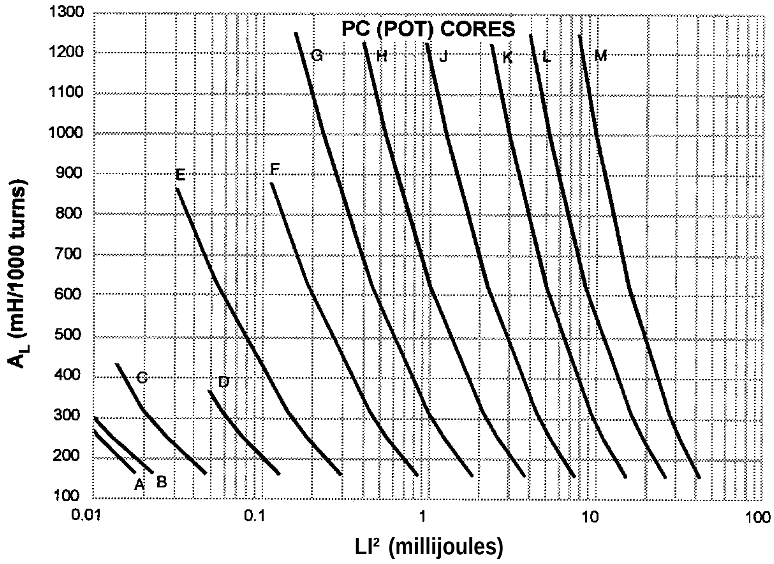
A_L	Turns
250	21
315	19
400	17

8. Use #14 wire.

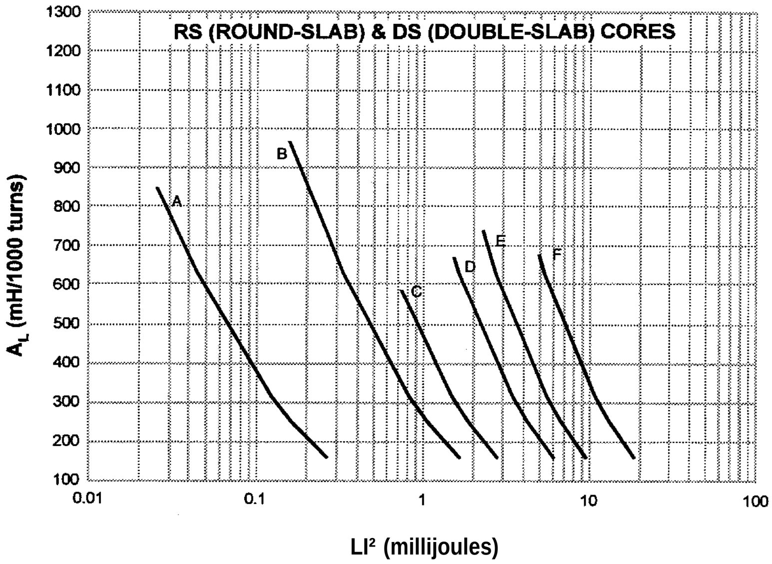
Note: MAGNETICS® Molypermalloy and Kool Mu® powder cores have a distributed air gap structure, making them ideal for switching regulator applications. Their dc bias characteristics allow them to be used at high drive levels without saturating. Information is available in catalogs MPP-303, KMC-01 and Brochure SR-IA.

FOR REFERENCES, See page 14.1.

Ferrite DC Bias Core Selector Charts



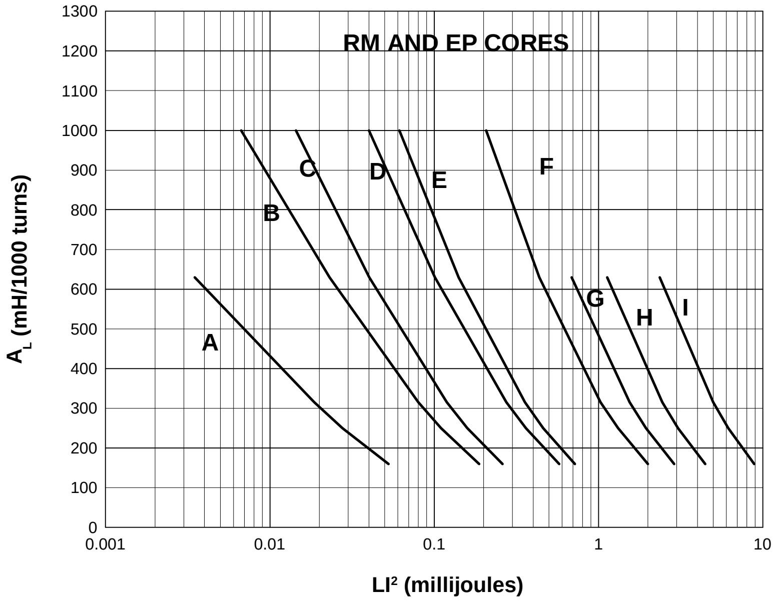
A- 40903
B- 40704
C- 40905
D- 41107
E- 41408
F- 41811
G- 42213
H- 42616
J- 43019
K- 43622
L- 44229
M- 44529



A- 41408 (RS)

B- 42311 (DS, RS)
42318 (DS, RS)

C- 42616 (DS)
D- 43019 (DS, RS)
E- 43622 (DS)
F- 44229 (DS)



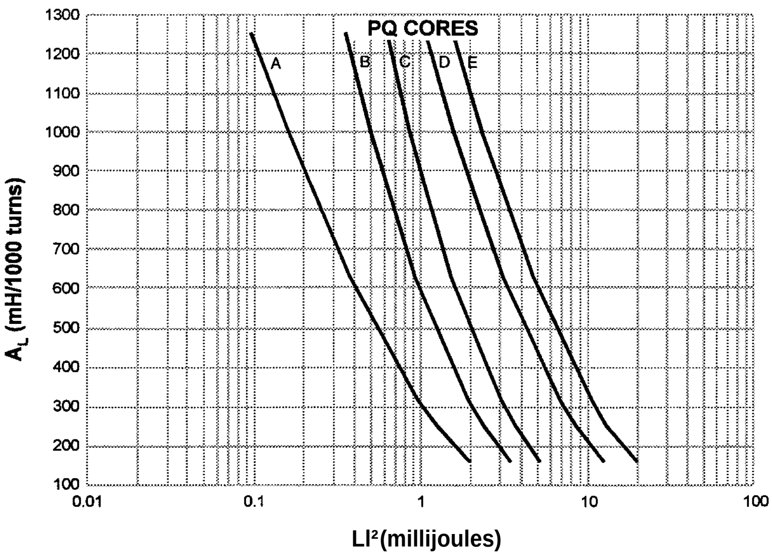
A- 40707 (EP7)
41010 (EP10)
41110 (RM4)

B- 41313 (EP13)
C- 41510 (RM5)
D- 41717 (EP17)
E- 41812 (RM6)
F- 42316 (RM8)
G- 42120 (EP20)

H- 42809 (RM10 planar)
42819 (RM10)

J- N43723 (RM12)

Ferrite DC Bias Core Selector Charts



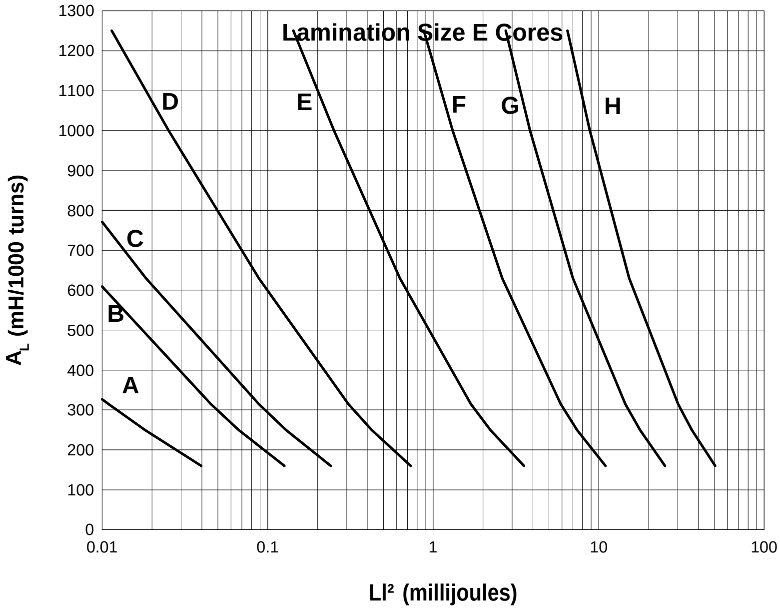
A- 42016
42020

B- 42614

C- 42610
42620
42625
43214

D- 43220
43230

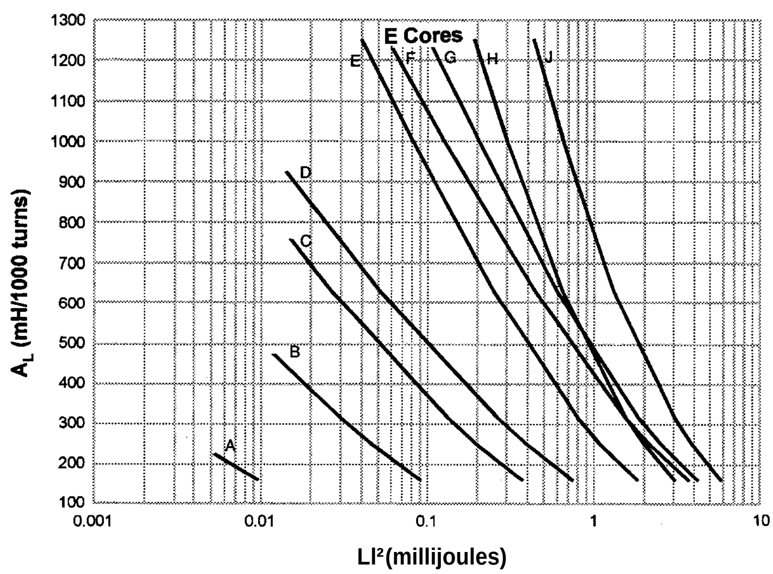
E- 43535
44040



A- 41203 (EE)
B- 41707 (EE)
C- 41808 (EE)
D- 42510 (EE)

E- 43009 (EE)
43515 (EE)

F- 44317 (EE)
G- 44721 (EE)
H- 45724 (EE)



A- 40904 (EE)

B- 41208 (EE)
41209 (EE)

C- 41205 (EE)
42211 (EE)

D- 42515 (EE)

E- 41810 (EE)
43007 (EE)

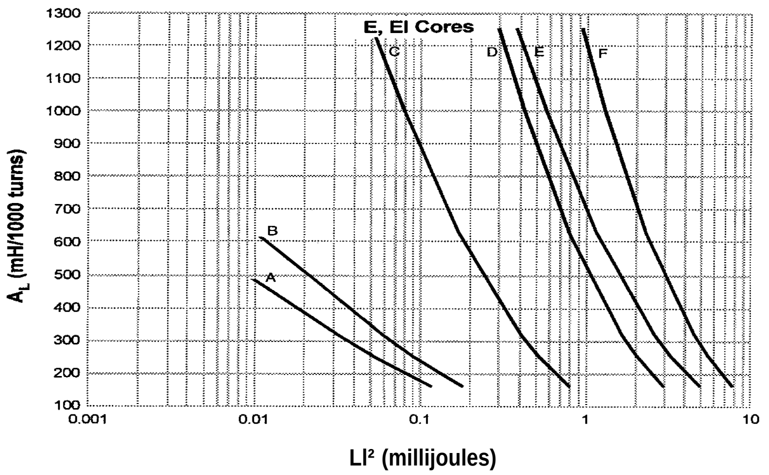
F- 43524 (EE)

G- 42530 (EE)
43520 (EE)

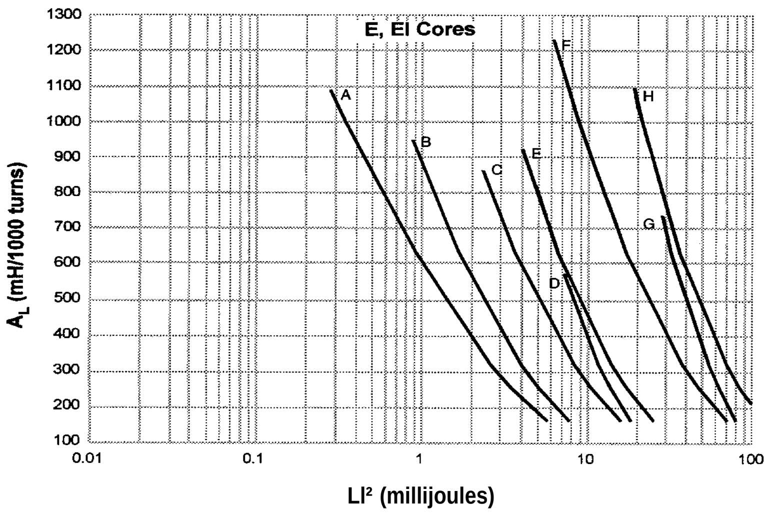
H- 42520 (EE)

J- 42810 (EE)
43013 (EE)

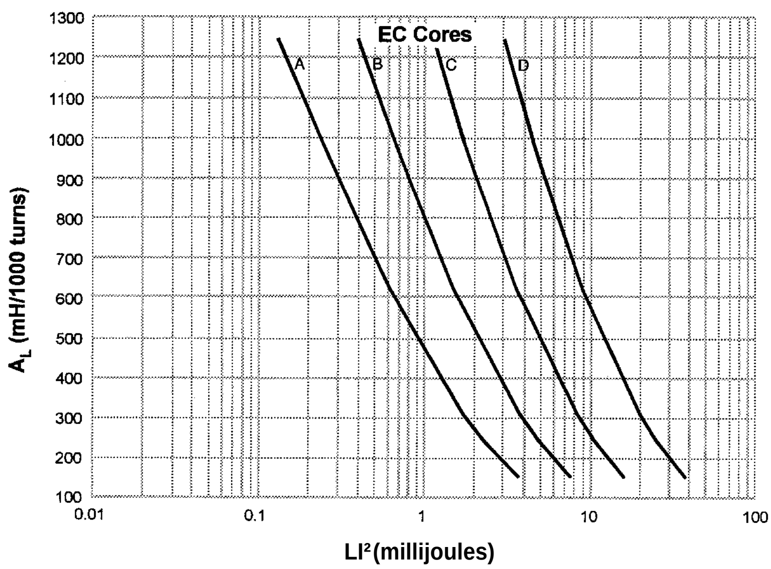
Ferrite DC Bias Core Selector Charts



A- 42110 (EE)
B- 41709 (EE)
C- 41805 (EE, EI)
D- 42216 (EE, EI)
E- 44008 (EE, EI)
F- 43208 (EE, EI)
43618 (EE, EI)

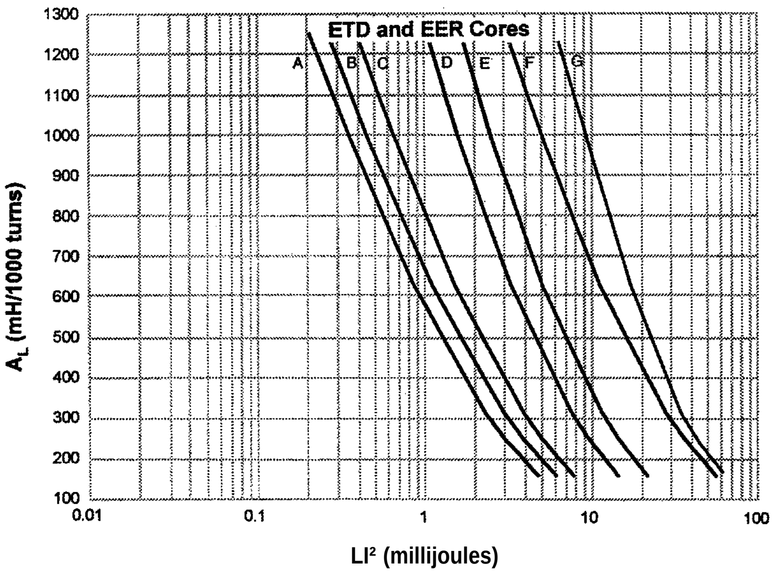


A- 44016 (EE)
B- 44011 (EE)
C- 44020 (EE)
D- 44308 (EE, EI)
E- 44022 (EE)
44924 (EE)
45021 (EE)
46016 (EE)
F- 45528 (EE)
45530 (EE)
47228 (EE)
48020 (EE)
G- 46410 (EE)
H- 49938 (EE, EI)

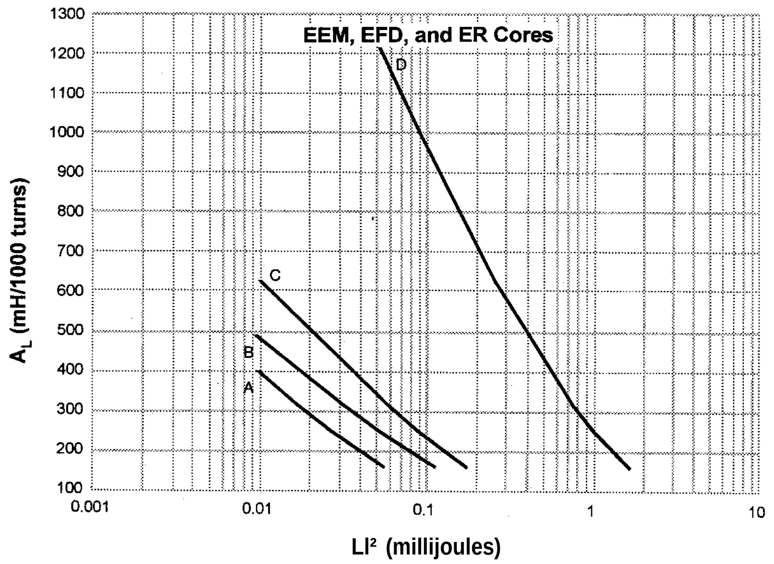


A- 43517
B- 44119
C- 45224
D- 47035

Ferrite DC Bias Core Selector Charts



A- 43434 (ETD34)
B- 43521 (EER35L)
C- 43939 (ETD39)
D- 44216 (EER42)
44444 (ETD44)
E- 44949 (ETD49)
F- 47054
G- 45959 (ETD59)



A- 41309 (EEM12.7)
40906

B- 42110
41515 (EFD15)

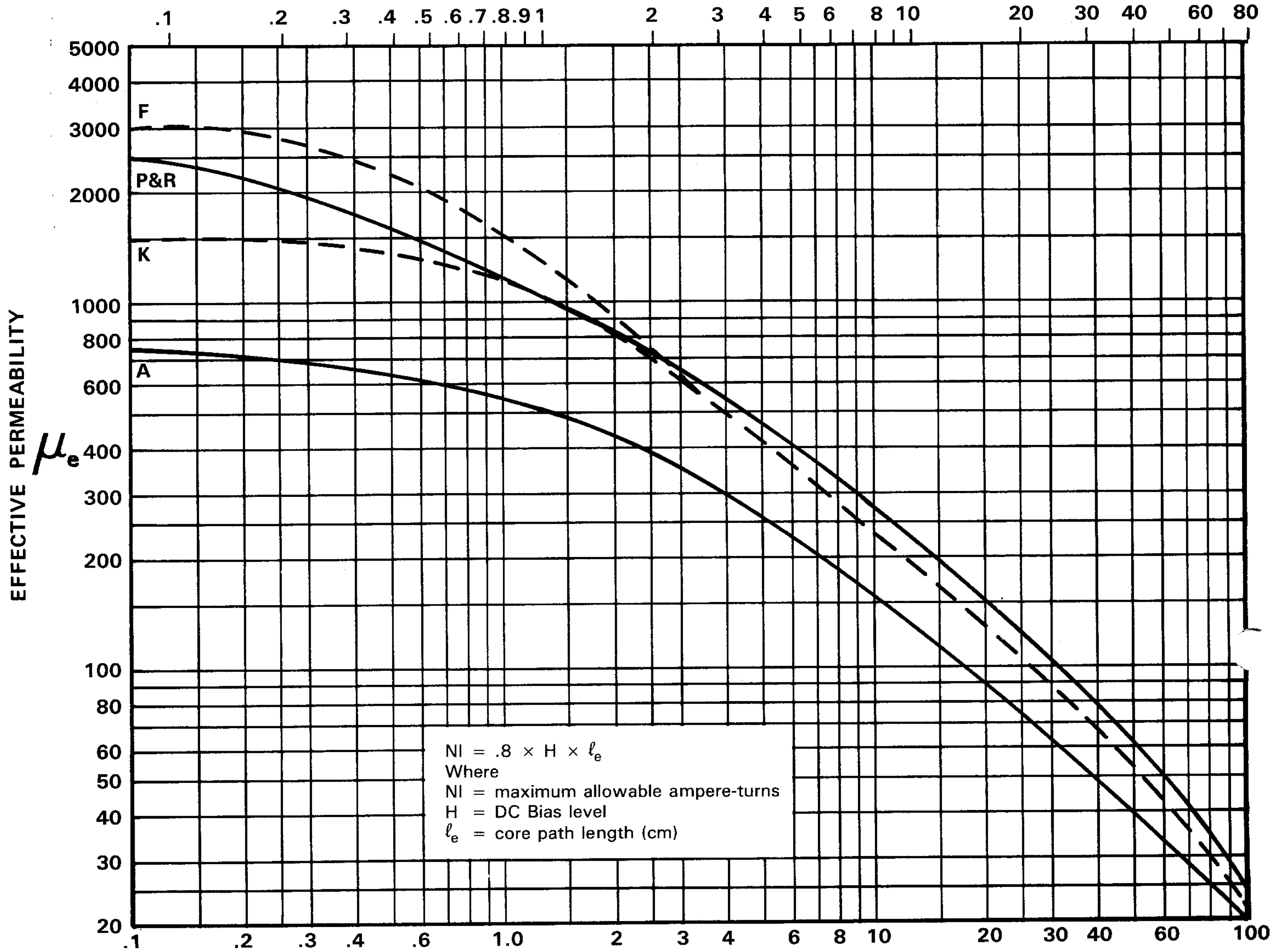
C- 41709

D- 42523 (EFD25)

Graph 4: For Gapped Applications — DC Bias Data

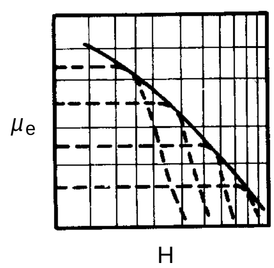
μ_e vs. H

H (Ampere-turns/cm)
(See bottom of graph for Oersteds)



H(OERSTED)
(See top of graph for Ampere-turns/cm)

The above curves represent the locus of points up to which *effective permeability* remains constant. They show the maximum allowable DC bias, in ampere-turns, without a reduction in inductance. Beyond this level, inductance drops rapidly.



Example: How many ampere-turns can be supported by an R-42213-A-315 pot core without a reduction in inductance value?

ℓ_e = 3.12 cm μ_e = 125
Maximum allowable H = 25 Oersted (from the graph above)
NI (maximum) = .8 x H x ℓ_e = 62.4 ampere-turns
OR (Using top scale, maximum allowable H = 20 A-T/cm.)
NI (maximum) = A-T/cm x ℓ_e
= 20 x 3.12
= 62.4 A-T

$$\mu_e = \frac{A_L \cdot \ell_e}{4\pi A_e}$$

$$\frac{1}{\mu_e} = \frac{1}{\mu_i} + \frac{\ell_g}{\ell_e}$$

A_e = effective cross sectional area (cm²)
A_L = inductance/1000 turns (mH)
μ_i = initial permeability
ℓ_g = gap length (cm)